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ABSTRACT

A static linear programming formulation (management tool) of energy optimization problems on military bases has been developed to assist each of the military services in their planning activities and budgetary allocation decisions. Several objective functions have been defined, resulting in two types of model capabilities: minimization of capital costs (investments) subject to a number of energy and dollar constraints and the maximization of energy savings subject to capital and operating fund budget restrictions and minimum energy performance goals. The management tool defines various levels of aggregation in terms of (1) geographical boundaries, (2) end-use energy demand, (3) building type characteristics, (4) conservation options, (5) renewable energy and alternative fuel technologies, and (6) a limited set of advanced energy technology options.

Both a technical description of (technical completion report) and a user's guide to the principal model components and operational attributes of the constructed DOD energy optimization model are presently being prepared. Two key questions are briefly reviewed within the context of preliminary results obtained from application of the developed model to two AFLC installations: (1) the geographical distribution of military construction dollars under a set of budgetary and energy performance constraints; and (2) the selection of energy supply technologies--conventional, conservation, renewable, and advanced--that simultaneously meet demand at least cost and satisfy a set of conflicting energy and budgetary goals. Temporal aspects of the problem are handled on a year-by-year basis, with information from a previous year's "optimal" investment and associated energy savings included in each succeeding year's decision criteria. Benefits and costs of the budgetary and energy allocation results are evaluated as part of the allocation decisions.

1. INTRODUCTION

1.1 Background

The Department of Defense (DOD) has adopted an ambitious program, called the Military Construction Program (MCP) to reduce energy consumption at fixed facilities, to convert existing boilers from

petroleum-based fuels to coal and coal-derived products, and to adopt advanced and renewable energy technologies for DOD installations as they become technically and economically feasible. These technologies include coal and nuclear power generation facilities as well as many non-conventional technologies. Executive and DOD wide memorandums have been published that establish energy management goals and objectives. These goals and objectives are designed to ensure continued progress in the adoption of conservation and renewable technologies. With the advent of an increasing number of conservation options and renewable energy technologies, important and key programmatic decisions must be made concerning the optimum allocation of limited resources (dollars) for energy research and development (R & D) and the military construction program (MCP).

A study was funded to develop a management tool capable of providing information concerning the optimal disbursement of available funds to assist the military services in efficiently allocating funds for energy conservation and the adoption of renewable and advanced technologies. The study has been funded equally by three military services: the U.S. Army, represented by the Office of the Chief of Engineers; the U.S. Navy, represented by the Civil Engineering Research Laboratory; and the U.S. Air Force, represented by the Air Force Engineering and Services Center. The Air Force has served as the lead service. The management model was applied to two of the Air Force Logistics Command Installations. The developed tool is equally applicable to all installations of the three services.

1.2 Objective

The objectives of the study were three-fold:

(a) Develop an optimization tool for the efficient allocation of military construction dollars among a variety of technologies and military installations;

(b) Define the required load and resource data needs to support the optimization tool; and

(c) Prepare a complete, self-contained optimization package, to include needed documentation, for use by the military services.

These three study objectives were further restated to include:

(d) A set of common energy demand and supply assumptions for use by the optimization tool; and

(e) The needed functions or relationships that will allow easy regionalization of the default (base case) assumptions. Both (d) and (e) were necessary to ensure that an operational model would be delivered to the three military services.

1.3 Principal Questions

The study requires development of a management tool which allows for an efficient allocation of limited budget dollars in both renewable and advanced energy technologies and energy conservation options across all military bases. The model can also be used to allocate funds within a given base or region. Two principal and distinct questions which the management tool can help answer are:

(a) What is the maximum energy savings that can be achieved for a given budget constraint (MCP dollar limitations, for example)? and

(b) What is the minimum cost of achieving a specific level of energy savings (goals and targets)?

These questions are interrelated. For example, the minimization of capital costs (MCP investments) will be subject to the same energy savings goals and targets that serve to govern the selection of technology options under the maximization of energy savings criteria. Although the former question underlies most of the military's activity in both evaluating and programming energy saving projects, it is the second question that more nearly addresses the military's ability to reach the energy use posture set forth by recent policy statements. Both questions play a key role in the final formulation of the management tool.

1.4 Outline of the Report

The remaining sections of the paper provides a technical description of the completed management tool. Section 2 presents a basic overview of the developed management model itself. The overview provided in section 2 is designed to be adequate for a good general understanding of the management tool.

Its structure, capabilities, and general data requirements are addressed. Section 3 provides an illustration of the use of the management tool for two AFLC bases. Geographic and technological components of the solution are briefly reviewed, with differences between the two bases noted. Future extensions of the DOD energy optimization model are also discussed, as are some of the limitations to its use.

2. MANAGEMENT MODEL OVERVIEW

2.1 Structure

The energy management model that has been developed results in the optimization of energy supplies given a well defined energy use goal. The basic structure of the model is portrayed in Fig. 1. The left-hand portion of Fig. 1 defines the pre-processor portion of the model. One result of this portion of the model is the specification or characterization of the physical and economic performance of each supply alternative (conventional, conservation and advanced/renewable energy supplies). The other result is the specification of a set of demand coefficients for each of ten building types and five energy end-uses. The building types, energy end-uses, conventional fuels and alternative energy options developed for use in this study are listed in Table 1. The demand and supply information is used to generate an input file for the linear programming (LP) model. The optimal solution(s) to the linear objective function is used to define the optimal set of energy supplies. This set of energy supplies meet the annual energy demands of the bases given the energy goal. The set of energy supplies are consistent with the constraints imposed in the LP section of the management tool.

The right-hand side of Fig. 1 defines the post-processor portion of the energy management model. This segment of the model uses both the inputs and outputs (optimal solution) of the LP computer approach to construct a series of tables which highlight the model's results. These tables are an integral part of the interpretation of the optimal solution(s).

The information in these tables is also used to define a new starting point for the second (or later) year of analysis. In this way the management tool is transformed from strictly a static LP model into a tool with dynamic properties. The first year starting point is defined with all energy demands being met through conventional energy sources. The first year's solution contains both conventional and alternative energy sources. The first year's solution serves as the starting point in year two and so on.

The management tool in its entirety is a series of data files and FORTRAN computer programs coupled with a linear programming (LP) computer package. The data files and programs are displayed and documented in the larger technical completion report and companion user's guide (previously referenced). The remainder of this section will be devoted to an examination of the demand, supply, accounting, bounds and constraint components of the model.

2.2 Components

Demand - The energy used in any set of buildings with similar functions on a base is defined as that building type's demand for energy. This demand has been segmented into five categories of energy end-uses (see Table 1). In general, the demand for energy exhibited by any set of buildings is either measured or estimated. For the purposes of this study it was necessary to estimate the demand component of the model because only minimal metering data is available. Generalized demand coefficients were estimated using energy audit information derived from previous studies of U.S. Army bases. These coefficients were defined for seven building types and five energy end-uses. Informed judgement was used to expand the number of building types to ten. This set of coefficients represents the average energy use per square foot of building floor space. The electrical end-uses are measured in kilowatt hours (kwh); the non-electrical end-uses are measured in British thermal units (Btu). The generalized coefficients are then combined with information on the building inventory (ft^2 of floor space) to estimate the total energy demand by each energy end-use category for each building type.

Complete records of the fuels and electricity purchased (both physical quantities and dollars) over the past years exist. These fuel purchase records are used to adjust the generalized demand coefficients such that the energy demand estimate coincides with the energy that was actually purchased. These adjusted energy demand coefficients become one input to the DOD energy optimization LP model itself.

Supply - Five conventional fuel types are used in this study (see Table 1). The base fuel purchasing records mentioned above are used to establish the proportion of energy demand that is presently met by each type of conventional fuel. This proportion is assumed to be constant for all building types. The base specific adjusted energy

demand coefficients, building type inventory, and fuel type proportions are combined to provide an estimate of the amounts of each conventional fuel presently being supplied to every building type. The use of the adjusted energy demand coefficients insures that the total energy demanded by a base will be exactly equal to the energy supplied (purchased). The price of each fuel in conjunction with estimated fuel use is used to calculate the cost of fuel for each building type.

Conservation measures are defined in this study as an alternative energy supply because, when properly implemented, conservation measures offset or satisfy the demand for energy in the same way that the use of conventional energy does. The generic conservation options included are listed in Table 1. A more detailed examination of the conservation performance and cost estimation procedure, with documentation, can be found in the two previously cited reports.

The generic conservation measures adopted for this study were judged to be those that have relatively high energy savings potential, reasonable payback periods, and those that are generally applicable to most building types (Table 1.). These conservation measures represent a subset of measures for which generalized physical and economic characterizations could be developed. The generic conservation measures fall into specific project categories developed by the Department of Defense for use in planning energy conservation retrofit projects for military use installations.

The physical performance and cost of the generic energy conservation measures were estimated through the use of equations and "base case coefficients" that employ climatic parameters. The actual development of the base specific coefficients is presented in the two previously cited reports. Typical building profiles, current energy consumption, and overhead and profit determination were incorporated into the equation (coefficient) estimation procedure. The energy savings (both electrical and fuel) and the development of the cost equations were specific to each generic conservation measure. Each measure involves a series of assumptions that were necessary in order to derive the generalized equations used to regionalize physical performance and economic costs. The assumptions were defined by careful examination of the available literature on building profiles for military bases and through the use of informed judgement.

There are numerous alternative methods of supplying energy. The broad groupings or categories considered in this study are listed in Table 1. Specific alternative systems or methods were chosen after a careful search of the relevant literature. When multiple or duplicate systems were found, one representative system was chosen. Pertinent information from the literature was used to construct the "base case" physical performance and the economic cost of each system used by the pre-processor to develop base specific coefficients. The regionalized coefficients were based upon climatic and construction cost index parameters specific to each base (addressed below). More detail on the coefficient development process can be found in the two previously cited reports.

Once a set of alternative systems has been specified, two subsets must be identified. The first subset is the group of alternative energy systems for which performance is not related to the location of the system. An example of this type of system is a nuclear power

generator. The second subset is the group of all systems for which the performance is related to the system's specific location. An example of a system in this subset is a solar hot water heater. A series of regionalization equations (dependent upon base climatic conditions) were derived for the second subset of systems so that the performance of the system could be estimated for each base.

The coal combustion technologies exhibit regional cost differences which are a function of the sulfur content of the coal and the air pollution control requirements. These considerations are included in the regionalization procedure(s). All system costs are corrected for regional differences by use of appropriate construction cost indices.

Some of the alternative energy systems considered in this study are building specific; an example of this type is a flat plate solar collector used to heat a building. This system is physically attached to the building. Buildings for which such a system is appropriate must be specified. This was done with some knowledge of the average sizes of buildings in each of the functional use or building type categories. Systems that are not building specific are those which supply some form of energy to the 'grid'. Energy can be supplied to any building type from the grid. An example would be a large wind generator. The end result of the regionalization procedure is a specification by building type (or grid designation) and by alternative energy option of base-specific physical performance and economic cost characterizations.

Accounting/balancing- The notion of the accounting and balancing relationships in the LP portion of the energy management model allows for the tracking and specification of key characteristics in an optimal solution. Aspects of an optimal solution include the total fuel savings, the types and "production" levels of alternatives to conventional fuel use that accomplish these fuel savings, the level of remaining conventional fuel, the cost(s) of implementing an optimal solution and the net benefits of that solution. The accounting is performed on both a regional and national level.

The value of the accounting variables is that they summarize the information used by the post processor portion of the management model. The information is also used to evaluate "success" in meeting energy use goals. Energy use is summed by alternative energy supply for each military category. Thus, it is a relatively easy task to calculate the proportion of total energy demand supplied by each of three categories; conservation, solar, and coal. The accounting variables are also used to verify that energy demands and supplies are equated in the optimal solution. As with the previous components greater detail on the accounting and balancing relationships can be found in the two previously cited reports.

Constraints and objectives - The constraints and objectives of the management model are defined in many ways. The equation which governs the solution of the LP formulation is generally referred to as the objective function. It is this objective function that is optimized in the LP portion of the model. One possible objective function is the energy savings equation. Each alternative to the conventional energy supplies contributes to the value of the energy saving function (equation) through offset fuel use. When the question to be addressed is the maximization energy savings, the solution

represents the maximum energy savings attainable given the specified constraints. The LP portion of the management tool can also be used to optimize other objective functions. For example, one possible specification of the LP objective function is the minimization of cost subject to energy conservation targets. The solution to this problem represents the most economical way of achieving certain conservation goals. The solution will always be optimal; that is the maximization or minimization of some function subject to a set of constraints will be the best possible answer to the given question.

There are three types of constraints in the LP portion of the model; energy targets or goals, monetary or budgetary, and physical. Energy target constraints are used to specify the proportion of energy which must come from a designated energy source or supply option such as solar or wind. Monetary constraints generally define the upper limit of capital expenditures, operation and maintenance expenditures or both. The physical constraints are used to guarantee that the activities included in the optimal solution are possible. For example, the square footage of solar roof collectors chosen for specific building types cannot exceed some reasonable proportion of the average roof size for that building type. These physical constraints are used to define reasonable "technical fit" limits for the optimal solution.

Bounds on supply activities - The supply activities are "bounded" to insure that the activity levels in an optimal solution are reasonable. Conventional supplies are bounded so that no more than the base year amount of conventional energy is allowed (conventional energy use must not exceed base year purchases). The conservation activities are bounded so that only reasonable levels are allowed in any building type in the optimal solution. Building specific systems are bounded by reference to the number of buildings which would be available on any given base. As with the other model components information on the bounding procedures can be found in the two previously cited references.

Dynamic aspects of the model - The LP portion of the model provides for a single year or a multi-period optimization of the objective function subject to a series of constraints. The overall management model is dynamic in the sense that the solution for year one can be used to define the starting point in year two; the second year solution can be used to define the starting point in year three and so on. This process can be used to exercise the management model for 2, 5, or more years. The previous years solution(s) will always be incorporated into the definition of a new starting point for the subsequent year.

This dynamic procedure occurs in the post-processor. Figure 1 is an accurate representation for a one year solution of the model. To picture a two or more year solution sequence the post-processor is connected to the input data sets that are in turn used by the LP portion of the model in redefining the alternative energy activities existing at the beginning of year two or subsequent years. Some of the accounting relationships and bounds are also modified in the dynamic procedures of the post-processor.

3. PRELIMINARY RESULTS AND CONCLUSION

For illustrative purposes the management model was exercised for two military bases, one in the Rocky Mountain region and the other in the Southwest. The objective function that was used for this example was the maximization of total fuel savings given a ten million dollar military construction budget. The illustrative results presented here include an examination of the alternatives to conventional fuel use selected by the management model and distribution of the construction budget between the two bases.

Over seven million dollars worth of conventional fuels were replaced by conservation strategies and renewable energy options in this example. The replacement pattern was different for each base, as was the distribution of the construction budget. The first base had relatively low electricity rates. Very few electricity uses were replaced while the more expensive fossil fuels were entirely replaced. The conservation strategies which reduced demand were heating, ventilation and air conditioning system improvements and lighting control strategies. These two replaced demand for fuels and electricity. The bulk of fuel replacement was accomplished by installation of a biomass plant which supplies thermal energy to the base grid. These choices resulted in an energy savings on the first base of about 4.5 trillion Btu's in year one.

The second base had relatively low coal and electricity prices. These fuels were not replaced. The more expensive fossil fuels were replaced by two conservation strategies, heating, ventilation and air conditioning system improvements and lighting control options. These replaced both electrical and thermal energy demands. A biomass plant was used to replace the rest of the thermal demand no longer supplied by natural gas, propane or oil. Approximately 1.1 trillion Btu's was saved on the second base through the use of these alternatives.

The pattern of conventional fuel replacement depends on the relative prices of the fuels. The most expensive fuels are always replaced first. Military bases pay very little for electricity; unlike civilian consumers, so electricity is the last fuel to be replaced. The pattern of substitution also depends on costs. In this case the cost per Btu replaced is the figure of interest. The alternatives which add the most to the fuel savings function while contributing the least to the construction budget are the ones which appear in the optimal solution. This relationship helps to explain the differences between solutions for base one and base two. Lighting system improvements in hangars appear in the solution for base one while they appear in all non-residential building categories for base two. This result undoubtedly reflects relative prices or costs between the two bases. The biomass plant for base one is about twice the size as the one for base two; since coal is a relatively cheap way to supply thermal energy on base two, full replacement was not attractive so the biomass plant in the solution is small.

The preliminary results presented here are very limited in nature. The technical completion report includes results for seven Air Force Logistics Command bases. A series of different objective functions are evaluated. These include maximization of fuel savings and minimization of a construction budget given specific energy targets. The impact of the 'technical' fit constraints is tested along with other physical constraints. Sensitivity analysis is conducted to test the degree of the impact of such parameters as fuel escalation rates.

The full model entails a five year optimization, each year's solution being incorporated into the problem definition for the next year.

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REFERENCES

1) This paper briefly summarizes two larger Los Alamos National Laboratory Reports entitled: "DOD Energy Optimization Model: A Technical Completion Report" by Fred Roach, Christina Kirschner, Shaul Ben-David, Robert Neenan, Richard Lotspeich, Richard Salmon, John Baumgartel, and Ann Zinn (forthcoming Summer 1982) and "DOD Energy Optimization Model: A User's Guide," by Christina Kirschner, Fred Roach, Shaul Ben-David, and Richard Lotspeich (forthcoming Summer 1982).